Daring to try something different

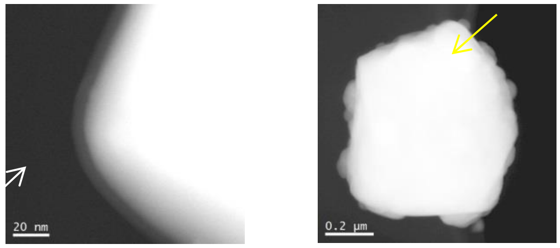
As an engineer that works in the area of Avionics Failure Analysis, Dr. Rolin is well aware that failure should never be seen as a negative. He has learned that failures always present situations from which individuals learn new ways of doing things that optimize processes, build character, and teach new pathways of problem solving. The innovation that is being submitted for award consideration encompasses building a solid-state ultracapacitor to replace batteries. This innovation was proposed two years ago to solve several problems NASA was having with batteries. Examples of these problems are that batteries contain harmful chemicals, they are bulky from a packaging perspective, they take a long time to recharge, and they are heavy. Dr. Rolin's proposed solution was to build a solid-state ultracapacitor that would avoid the hazardous chemicals, charge rapidly, and yet be packaged in a way that was small but robust enough to survive aerospace environments. This was a huge undertaking because he dared to create a device that was novel with very little supporting data in the literature. In addition, he was proposing to build the device using nanotechnology and additive manufacturing techniques that had not been tried. It was easy to understand why many had not attempted the challenge. It was daunting due to the number of variables that had to be controlled and the easy way out was to build on what others had already accomplished. His energy density goal was 100 joules/cubic centimeter, which would be an energy density approximately equal to NASA's Range Safety Battery.

Perseverance builds character

The work began by first tackling the materials problem. Dr. Rolin found one research paper where a thinly coated barium titanate nanoparticle was shown to increase permittivity (thus, would result in increased capacitance and hence increased energy storage) of barium titanate by an order of magnitude but they reported it was not very reproducible. The materials used were not nearly as hazardous as those used in batteries, and there was something interesting happening with the permittivity. He considered this to be a good starting point. He sought out a coating vendor, procured materials and began coating barium titanate nanoparticles with a variety of different materials at a variety of nanometer thick shell layers. The process was to vary the shell material and thickness, obtain the best sample characteristics and subsequently work from that sample forward. To make the measurement process easy, he began building devices using additive manufacturing techniques as well as other techniques to keep the layers of dielectric as thin as possible. Thin layers keep the electrode spacing small, which results in increased capacitance and hence increased energy storage. Dr. Rolin was seeing increases of permittivity by several orders of magnitude! He was also getting charging times not in hours but in seconds! However, the capacitance of the samples was not reproducible and was typically so small that the energy density was in the millijoules/cubic centimeter. Dr. Rolin was very far from his goal and by the time he had the materials selected, procured, coated, and devices built, the project had reached the end of its fiscal year funding. It would have been easy for him to stop at this point. He was miles from his goal and it looked like he was getting similar results as demonstrated in the research paper. However, something was there and he was determined to succeed. This technology was too important to NASA's long-term mass reduction and power goals.

Collaboration through diversity and inclusion

Dr. Rolin had failed to meet his energy density goals and this irreproducibility issue was troubling. As a materials scientist, he simply had to know why. He wrote a proposal for second year funding and was fortunate to be awarded a second year. He had learned from my previous mistake, that is, he had kept everything in-house. He needed others to get involved. He needed people with diverse backgrounds and fresh ideas. To accomplish this, Dr. Rolin sought out materials experts from outside NASA in both academia and industry to help characterize what was happening at the nanoscale level. This "lessons learned" began to pay dividends immediately. One of the experts had determined that the furnace being used to sinter the dielectric was randomly poisoning the devices with oxygen very late in the device manufacturing stage. He helped find and fix the oxygen leak in the furnace. Another expert, in charge of examining the shell thickness, was finding that the coating was diffusing into the core during device manufacturing (Figure 1). This was due to the high temperature inks being used to make electrodes. In other words, he was heating the device at high temperatures to sinter the electrode ink and this was causing the shell to diffuse into the core. The random shell structure was destroying the ultracapacitor.

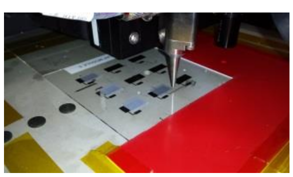


A B

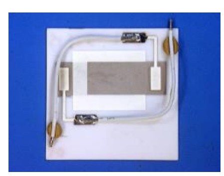
Figure 1. Collaboration with other experts helped Dr. Rolin get around one of his biggest failures . **A**. This image was taken before electrode sintering and shows what the shell should look like. It is uniform and consistent (white arrow). **B**. This image shows what was happening after sintering our electrode material. The shell has not only clumped but also diffused into the core (yellow arrow).

Learning from mistakes = spin-off technologies

Dr. Rolin had not even considered that sintering the electrode ink would cause the diffusion they were seeing. The temperatures were large enough, but he erroneously thought the time scales were sufficiently small as to avoid problems. Clearly, this was another unforeseen failure that led him to dare and try something new. That something new was to develop an electrode ink that would sinter at low temperatures but still be solderable in a way that commercial manufacturing would not be jeopardized. They had to develop it because such an ink did not exist. After spending several months in the lab, his team was finally able to produce the ink. The formulation and processes used to create this ink are in the stages of a New Technology submission for patent. If this spin-off technology leads to commercialization, it will help device manufacturers produce electrodes for a variety of devices at lower costs with less impact to their final components. This new ink has helped his team build better devices. They are currently at 1 joule/cubic centimeter and are now researching new core materials including doping and polymer hybrids. Although they still have a way to go, they are not as far away as they once were. We know that Dr. Rolin will continue to run into failures along the way but he has learned not to give up. Each step in this process has been and will continue to be a learning experience.



Additive manufacturing devices



Final device construction